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1 597 324

(54) INTEGRATED MAGNETIC FIELD SENSOR

(71) We, N.V. PHILIPS' GLOEILAMPENFABRIEKEN, a limited liability Company, organised and established under the laws of the Kingdom of the Netherlands, of Emmasingel 29, Eindhoven, the Netherlands do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The invention relates to a magnetic field sensor, comprising an anisotropic magnetic layer which is magnetized in a preferred direction and which is surrounded by an electric coil to form an inductor the inductance of which depends on the permeability of the magnetic layer, an external magnetic field and the coil axis being aligned, in use, so as to be parallel to the preferred magnetic direction.

United States Patent Specification 3 443 213 describes a thin-film magnetic field sensor, the measuring coil axis being disposed parallel to the direction of the "hard" axis and a magnetic bias field being oriented in accordance with the "easy" axis, the fields to be measured being also oriented in accordance with said "easy" axis. The thin magnetic layer, which consists of an Ni-Fe compound, is manufactured by deposition on a glass substrate and during manufacture it is exposed to a strong homogeneous magnetic d.c. field, which is applied in the plane of the substrate. The orientation of this field determines the so-called "easy" axis, whilst the axis which is perpendicular thereto is referred to as the "hard" axis because the layers exhibit a preferred direction of magnetization oriented in accordance with the "easy" axis (uniaxial anisotropy).

A magnetic field sensor is known in which a thin magnetic layer, which is magnetized in a preferred direction, is surrounded by a coil to form an inductor the inductance of which depends on the permeability of the magnetic film, an external magnetic field to be measured and the coil axis are aligned so as to be parallel to only one direction referred to the preferred direction, a magnetic bias field of the order of magnitude of the anisotropic field strength being applied substantially in the direction of the "hard" axis of the magnetic layer and the coil axis being aligned so as to be parallel to the "easy" axis of the layer, so that the inductance of the measuring coil is changed only as a result of variations of components of the magnetic field to be measured in the direction of the "easy" axis. The magnetic layer is surrounded by a wound coil. As the layer and coil are physically separated from each other, the sensor is sensitive to mechanical shock or vibration and, owing to the substrate thickness, which is very large in comparison with the magnetic layer, the sensitivity of the sensor is considerably reduced. Furthermore, the manufacturing process of the sensor is complicated and expensive.

It is the object of the invention to realize a magnetic field sensor as an integrated element, whilst avoiding said drawbacks.

In accordance with the invention there is provided a magnetic field sensor comprising an anisotropic magnetic layer which is magnetized in a preferred direction and which is surrounded by an electric coil to form an inductor the inductance of which depends upon the permeability of the magnetic layer, the axis of the coil being parallel to the preferred direction, wherein the sensor is formed on an insulating substrate as a series of layers thereon, namely a first layer of electrically conductive strips extending parallel to each other, a first electrically-insulating layer covering all but the free ends of the strips, the said magnetic layer, which is formed as a sandwich layer comprising a plurality of magnetic films with

intervening electrically-insulating films, a second electrically insulating layer covering the sandwich layer but not the free ends of the strips, and a second layer of electrically conductive strips extending parallel to each other and so arranged that the ends of the strips of the first layer contact respective free ends of the strips of the first layer to form said electric coil.

An embodiment of the invention will now be described with reference to the accompanying drawings, of which:

Figure 1 shows a cross-section of part of a magnetic field sensor,

Figure 2 shows copper strips formed in separate layers and joined at their ends to a form a so-called flat coil,

Figure 3a shows a cross-section of a copper strip having undesirably-steep edges,

Figure 3b shows a preferred form of the strip with less steep edges, and

Figure 4 shows a cross-section through a complete sensor.

In the part of the sensor shown in Figure 1, a film, preferably of copper and having a thickness of a few μm, is first applied on a substrate S. It may be necessary to fix the copper film to the substrate with the aid of a so-called adhering film H_1, H_1', for example of NiCr or Ti and 0.1 μm thickness. With the aid of a photolithographic process, parts of the copper film are etched away in such a way that a row of parallel narrow strips is obtained, which strips form conductor tracks L_1 (see also Figure 2).

On these tracks L_1, a dielectric film D_1 (for example of SiO_2 or an organic polymer) of a thickness of a few μm is deposited. As the ends (not shown in Figure 1) of the copper conductor tracks should not be covered with the dielectric, it is advisable to deposit the dielectric film D_1 through a mask. In order to obtain a dielectric film D_1 with bevelled edges (see also Figure 4), it is again suitable to use a photolithographic process followed by an etching operation.

A magnetic layer M is deposited on the dielectric layer D_1 by a suitable method, preferably by cathode-sputtering. Deposition is suitably carried out by sputtering through a mask, to obtain the desired pattern. Preferably, NiFe (81:19) or MoNiFe (4:79:17) is used as magnetic material. The magnetic layer M is a so-called sandwich layer comprising a plurality of films which alternately consist of a magnetic material (preferably of 0.8 μm thickness) and a dielectric (preferably of 0.3 μm thickness). Suitably, the complete sandwich is manufactured by a vacuum-coating process. Application of the magnetic films is suitably effected in an external magnetic field of 20 to 50 Oersted, in order to impress a preferred magnetic direction of the sandwich film.

It has been found that vacuum-deposited or sputtered magnetic films partly lose their desirable magnetic properties (anisotropy and low coercive force) if the surface of the underlying layer is rough or has a sharp edge. It is therefore preferable that the copper conductor tracks L_1 which are deposited underneath the magnetic layer M are not steep-edged as shown in Figure 3a, but are preferably bevelled, with the aid of a slope-etching process, as shown in Figure 3b. The bevel angle is preferably less than 30°.

On the sandwich layer M, a second dielectric layer D_2 is deposited, whose thickness and shape substantially correspond to the layer D_1 so that the exposed ends of tracks L_1 are not covered. The second conductor-track film L_2 is superimposed on the layer D_2 with an optionally interposed adhering film H_2. This film L_2 preferably also consists of copper; and is etched away to form conductor tracks the ends of which contact the conductor-track film L_1 (see Figure 2) to form a closed flat coil with the tracks of the conductor-track layer L_1, which coil surrounds the magnetic sandwich layer M. It is essential that the edges of the insulating layers D_1 and D_2 are not steep but bevelled, so as to ensure satisfactory coverage by the conductor-track layer L_2, as can be seen in Figure 4.

Since the sensor comprises a series of consecutively deposited layers, a large number of sensors can be simultaneously manufactured in a batch proces. In such a batch process, series of substrates are simultaneously subjected to one specific manufacturing step at a time, *i.e.* a large number of substrates are at the same time subjected to a vacuum deposition, sputtering, or etching operation. In general, such batch processes enable an element to be manufactured in an inexpensive manner.

WHAT WE CLAIM IS:-

1. A magnetic field sensor comprising an anisotropic magnetic layer which is magnetized in a preferred direction and which is surrounded by an electric coil to form an inductor the inductance of which depends upon the permeability of the magnetic layer, the axis of the coil being parallel to the preferred direction, wherein the sensor is formed on an insulating substrate as a series of layers thereon, namely a first layer of electrically conductive strips extending parallel to each other, a first electrically-insulating layer covering all but the free ends of the strips, the said magnetic layer, which is formed as a sandwich layer comprising a plurality of magnetic films with intervening electrically-insulating films, a second electrically-insulating layer covering the sandwich layer but not the free ends of the strips, and a second layer of electrically

conductive strips extending parallel to each other and so arranged that the ends of the strips of the first layer contact respective free ends of the strips of the first layer to form said electric coil.

2. A magnetic field sensor as claimed in Claim 1 wherein the edges of the strips of the first layer of conductive strips are bevelled, the angle of slope of the edges relative to the substrate surface being less than 30°.

3. A magnetic field sensor as claimed in Claim 1 or 2 wherein the edges of the two electrically insulating layers are bevelled.

4. A magnetic field sensor as claimed in any previous Claim wherein the magnetic layer is deposited by cathode sputtering.

5. A magnetic field sensor substantially as herein described with reference to the accompanying drawings.

6. A magnetic field sensor as claimed in any previous Claim and manufactured in a batch process, as one of a plurality of such sensors.

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2 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 1

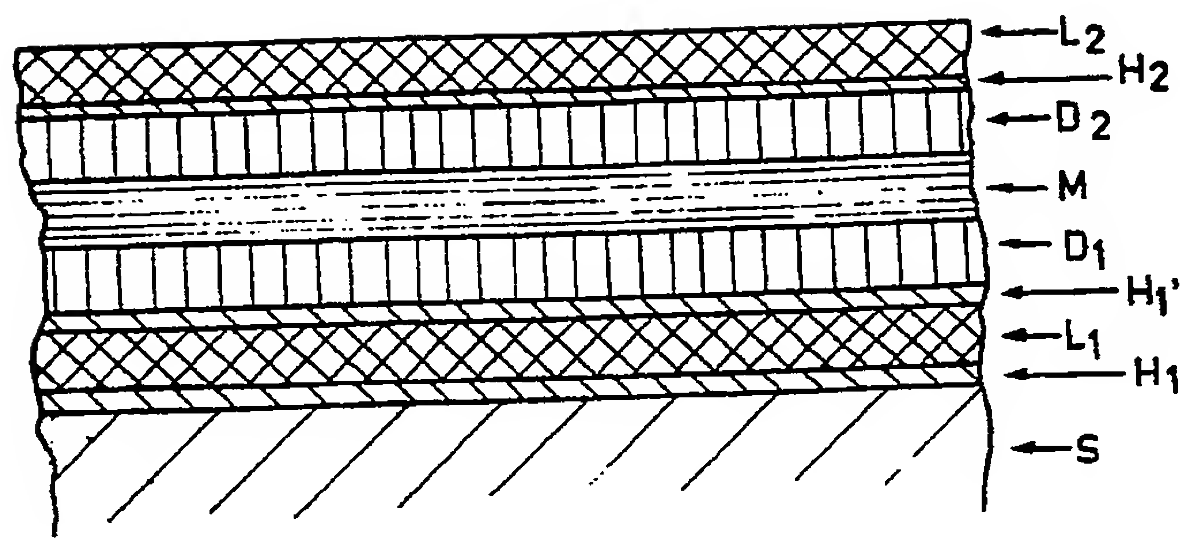

Fig.1

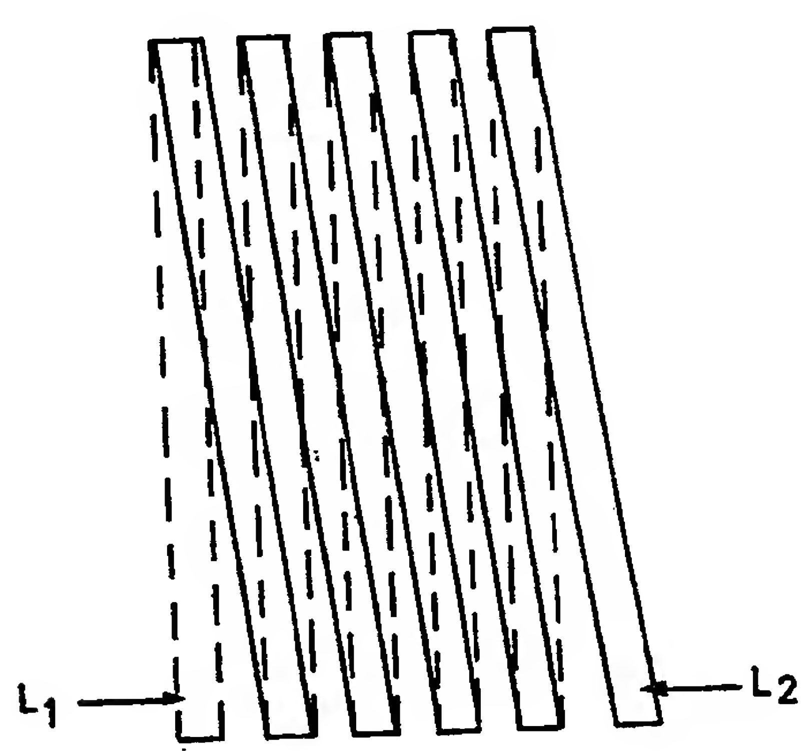

Fig.2

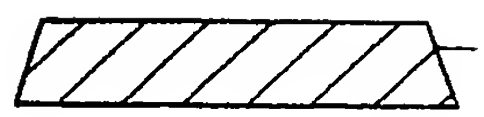

FIG.3a

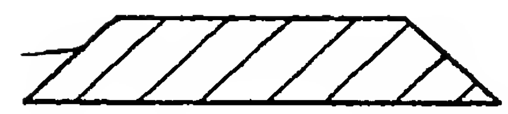

FIG.3b

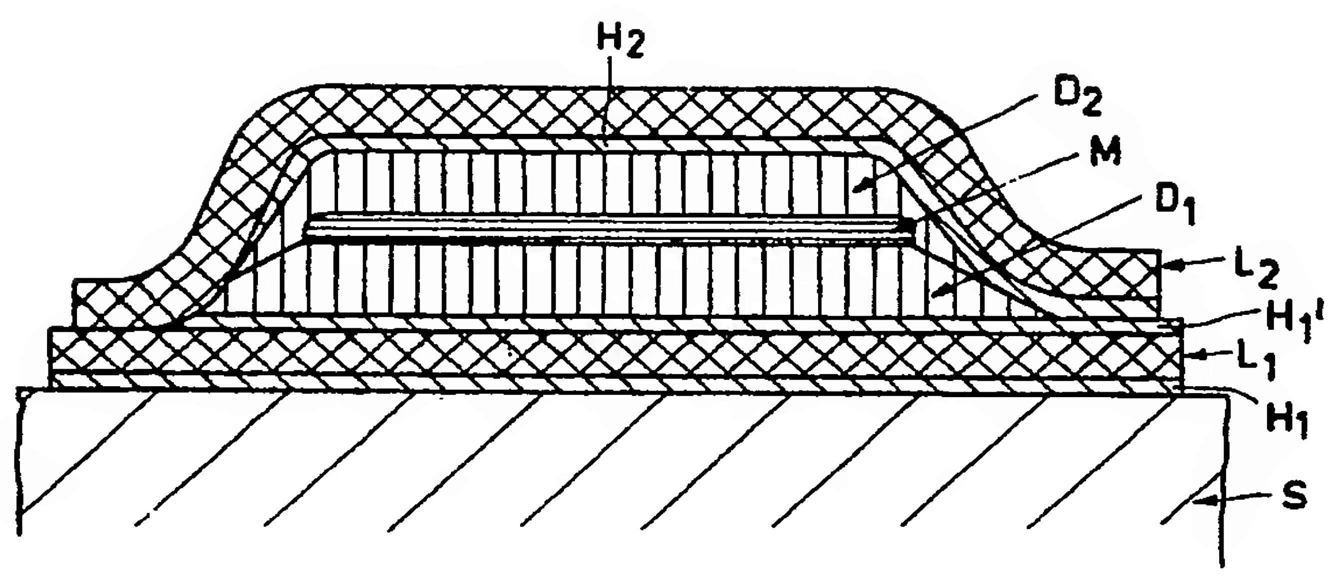

FIG.4